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CHANNEL ESTIMATION FOR LTE-MIMO SYSTEM

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ABSTRACT

High transmission data rate, improved system capacity, spectral efficiency, flexible bandwidth operations and reliability are essential for future wireless communications systems. MIMO is a bandwidth efficient technique for establishing high capacity communication system. RF spectrum is a finite resource. Hence, in order to generate more throughput from existing bandwidth technology such as LTE is used. LTE along with MIMO promises to significantly boost data rates and overall system capacity. Capacity gain can be enhanced by varying the number of transmitters or receiver antennas.

The gist of the paper is MIMO systems with correlated and uncorrelated channels and are acknowledged for different number of TX_N and RX_N antennas and different SNR over Rayleigh fading channel. We examine the utility of various channel capacity definitions, namely ergodic capacity and outage capacity. This paper proposes that by varying TX_N antenna, a considerable gain in the system capacity is obtained when fixing RX_N antenna. Also MIMO channel capacity will decrease when the correlated factor increase, but still we have a considerable gain in case when applying CSI technique.

KEYWORDS: CSI, LTE, MIMO & Rayleigh Fading

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Original Article

I. INTRODUCTION

Tremendously increasing demand on wireless communication services and due to scarcity of RF spectrum, channels capacity has becomes an important criterion in modern communication system [1]. Shannon's fundamental work on channel capacity relates the data rates to the transmission bandwidths. In low-bandwidth utilization, any increase of the data rate will require an increase in the received signal power in a proportional manner whereas for high-bandwidth utilization, any enhancement in the data rate will require a much larger relative increase in the received signal power [4].

To meet the demand of today's era in high speed communication systems, LTE (Long Term Evolution) has been developed. MIMO is a primary element in LTE system design. MIMO antennas brings many potential benefits to mobile radio systems, including more reliable operation in poor signal conditions, greater spectral efficiency (and hence overall system capacity) and increased data rates for individual users. MIMO has becomes vital area of research in wireless activities. Channel capacity can be efficiently improved by increasing TX_N, RX_N antennas without any

modification in the channel bandwidth or transmitted power. The rising key for high bit rate wireless services is the use of MIMO system.

II. TRANSMISSON MODEL FOR MULTIPLE-INPUT MULTIPLE-OUTPUT CHANNELS

Communication channel transmits information from a transmitter (TX_N) to a receiver (RX_N). Wireless channels exhibit multipath propagation within the transmitter and the receiver resulting in receiving different variants of the transmitted signal at the receiver [5]. These separate versions experience different path loss and phases. Different possible paths for the received signals are:

- Line of Sight (LOS)
- Absorption
- Diffraction
- Reflection
- Refraction
- Scattering

The transmission model for MIMO channel, TX_N transmitter antennas transmits signals simultaneously whereas RX_N receiver antennas receives the signal which are meant for it as well as a fraction of other signals [5]. Figure 1 depicts MIMO system. Thus, the channel response is indicated as a transmission matrix H . Thus, the channel matrix is of dimension TXN*RXN.

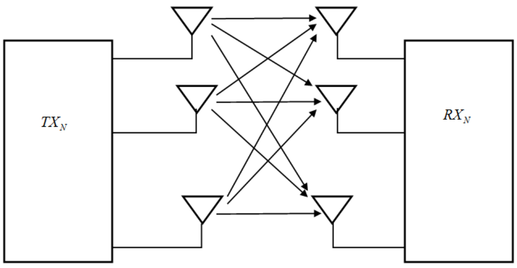

Figure 1: Multiple-Input Multiple-Output System

The straight route between TX_N and RX_N antenna can be expressed by channel response $h_{RX_N TX_N}$ .Figure 2 shows the received vector y is expressed in terms of channel transmission matrix H , input vector x and noise vector n as

$$y = Hx + n \tag{1}$$

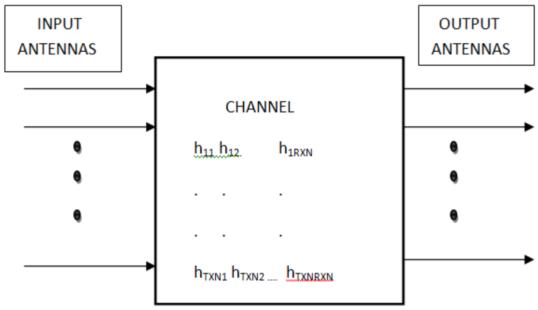

Figure 2: MIMO System from Channel Perspective

III. CHANNEL STATE INFORMATION

Transmission of uncorrelated data streams over multiple antennas depends on the correlation factor that measures the influence of spatially separated signals. Correlation in MIMO channel is important parameter by which system performance is affected strongly. It can be eliminated by employing orthogonally polarized antennas.

Increase in correlation results in decreasing system capacity. Hence, the transmission matrix also called as Channel State Information (CSI) technique was introduced to enhance system's capacity. In a SISO channel, the CSI is constant and does not change from bit to bit. Thus, the knowledge of CSI at transmitter or receiver will open up the opportunity of incorporating this information in intelligent system design.

IV. FADING CHANNELS

In a wireless channel, the signal travels between transmitter and receiver using multipath reflections. This gives rise to multipath fading, which causes fluctuations in amplitude and phase of the received signal. Such multipath fading channels are divided into slow fading/fast fading and frequency-selective/flat fading channels. Following are the fading models:

- **Rayleigh Fading Model:**

The delays correlated with different signal paths in a multipath fading channel varies in an erratic manner. When there are large number of paths, the central limit theorem can be applied to model the time-variant impulse response of the channel as a complex valued Gaussian random process. In Rayleigh fading channel, the impulse response is shaped as a zero mean complex valued Gaussian process.

- **Rician Fading Model**

Rician fading is identical to Rayleigh fading, except that in former a strong prevailing component is present.

V. CLOSED LOOP SYSTEM VERSUS OPEN LOOP SYSTEM

The communication system may be classified as

- **Open Loop System:** In this system, the transmitter cannot access CSI and has no awareness about the channel whereas the receiver may estimate the channel and use CSI for decoding.
- **Closed Loop System:** In this systems, the receiver sends some information about the channel back to the transmitter

through a feedback channel. The transmitter can use this information to improve the performance.

Figure 3 depicts open loop and closed loop MIMO system.

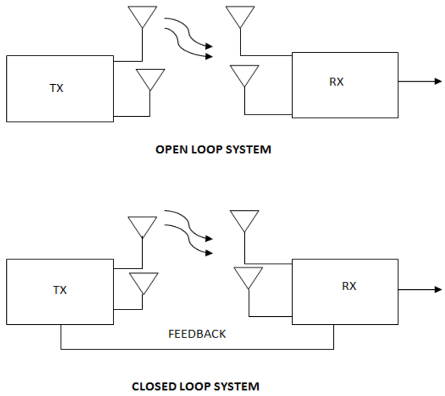

Figure 3: Open Loop and Closed Loop Sytem [5]

VI. CHANNEL CAPACITY

The channel capacity is defined as the maximizing of the bilateral information between the input and output given a power constraint P on the total transmission power of the input, that is $Tr(K_C) \leq P$, where

K_C **:** Covariance of the input C

$Tr(K_C)$ **:** Trace of a matrix K_C.

So, it is given by

$$C = \max_{Tr(K_C) \leq Tx_N} \log_2(\det[I_{Rx_N} + (\gamma/Tx_N)H^H.K_C.H])bits/sHz \tag{2}$$

The unit bits/(sHz) represents the fact that for a bandwidth of W, the maximum possible rate for reliable communication is CW bits/s.

For Open Loop System

In the case of an open-loop system, in which we do not have information about the channel at the transmitter, a good assumption is to distribute the input power equally among the transmit antennas. This results in a covariance matrix K_C that is a multiple of the identity matrix. Consider the constraint $Tr(K_C) \leq Tx_N$ we have $K_C = I_{Tx_N}$ that results in the following mutual information:

$$C_{EP} = \log_2(\det[I_{Rx_N} + (\gamma/Tx_N)H^H.H])bits/sHz \tag{3}$$

Where the subscript “EP” stands for “equal power.”

The equal power allocation among different antennas is optimal for the uncorrelated independent identically distributed Rayleigh fading channel.

The capacity in (3) can be calculated in terms of the positive eigen values of the matrix $H^H.H$. Let us define,

r **:** The rank of matrix H and

λ_i **:** The non-zero eigen values of the matrix $H^H.H$ and are positive real numbers where, i = 1, 2,..., r. The equal power channel capacity in (3) can be rewritten as

$$C_{EP} = \sum_{i=1}^{r} \log_2[1+(\gamma/Tx_N)\lambda_i] \tag{4}$$

For Closed Loop System

When the channel is known at the transmitter, that is a closed-loop system, a non uniform distribution of power among transmit antennas is useful. Using (2) and the singular value decomposition of H , one can show that in this case the capacity is

$$C = \max_{\sum_{i=1}^{r}\gamma_i=\gamma} \sum_{i=1}^{r} \log_2(1+\gamma_i\lambda_i) \tag{5}$$

The above capacity is calculated using a water-filling algorithm. Note that an equal distribution of the power, $\gamma_i = \gamma/Tx_N$, in (5) results in the formula in (4). If the channel is known at the transmitter, the capacity in (5) provides some increase over C_{EP} .This is due to two factors:

- The unequal power allocation among different antennas, the diagonal elements in K_C and
- The correlation in the optimal matrix K_C .

It can be concluded that the gain because of water-filling is mostly due to the correlation in the optimal matrix K_C . For an equal number of transmit and receive antenna, the capacity increase due to an optimal water-filling disappears at high SNRs.

Ergodic Capacity

The ergodic capacity is the maximum mutual information between the input and output if the code spans an infinite number of independent realizations of the channel matrix H . It is defined as:

$$C_E = E[\log_2(\det\{I_{Rx_N} + (\gamma/Tx_N)H^H.H\})] bits/sHz \tag{6}$$

Note that ergodic capacity (6) is in fact the mean of the capacity in (3).

Ergodic capacity exists for memoryless channel. Using multiple antennas increases the ergodic capacity. Also, the effect of multiple Rx_N antennas in increasing the ergodic capacity is more than that of the multiple Tx_N antennas. For a large number of transmitter antennas and a fixed number of receiver antennas, using the law of large numbers,

$$\frac{H^H.H}{Tx_N} \rightarrow I_{Rx_N} \tag{7}$$

As a result, the ergodic capacity is $Rx_N \log_2(1+\gamma)$ for large Tx_N.

Outage Capacity

The outage capacity C_{OUT} is a value that is smaller than the random variable C only with a probability P_{OUT} (outage probability). By fixing C_{OUT}, we can find P_{OUT}. The relationship between C_{OUT} and P_{OUT} is:

$$P_{OUT} = P(C < C_{OUT}) \tag{8}$$

The importance of the outage probability is that if one wants to transmit C_{OUT} bits/channel use, the capacity of the channel is less than C_{OUT} with probability P_{OUT}. Hence, such a transmission is impossible with probability P_{OUT}.

For a stationary channel, if we transmit a large number of frames with a rate of C_{OUT} bits/channel use, the number of failures is P_{OUT} times the total number of frames. On the other hand, since with a probability of $1-P_{OUT}$, C will be greater than C_{OUT}. The value C_{OUT} assures that it is possible to transmit C_{OUT} bits/channel using a probability of $1-P_{OUT}$. Of course, picking a higher outage probability for a fixed received signal to noise ratio results in a larger outage capacity. The above definitions of outage capacity and outage probability are valid for any number of Tx_N and Rx_N antennas.

One problem that arises in a multi-antenna system is the number of independent random variables that affect the Shannon capacity. For a Rayleigh fading channel with Tx_N transmit antennas and Rx_N receive antennas, the Shannon capacity is a function of Tx_N Rx_N independent complex Gaussian random variables. Following are the cases to be discussed:

- For $Tx_N = 1, Rx_N = 1$
- For $Tx_N = 1, Rx_N$
- For $Tx_N, Rx_N = 1$

For $Tx_N = 1, Rx_N = 1$

In this case, the capacity is

$$C = \log_2(1+\gamma.\chi) \tag{9}$$

Where, χ is a chi-square random variable with two degrees of freedom. In this case, to achieve one extra bit of capacity at high SNRs, one requires a 3 dB increase in signal-to-noise ratio (doubling the SNR).

For $Tx_N = 1, Rx_N$

For the case of one transmit antenna, that is $Tx_N = 1, Rx_N$ receive antennas, using the equality $\det[I + A.B] = \det[I + B.A]$, we have

$$C = \log_2(\det[I_{Rx_N} + \gamma H^H.H]) = \log_2(1 + \gamma H.H^H) \tag{10}$$

It is observed that the possibility of a diversity order of Rx_N exists for one transmit and Rx_N receive antennas.

For $Tx_N, Rx_N = 1$

Similarly with N transmit antennas and one receive antenna system the Shannon capacity can be calculated as

$$C = \log_2(1 + (\gamma/N).\chi_t) \tag{11}$$

Where, χ_t is a chi-square random variable with $2Tx_N$ degrees of freedom. The corresponding formula for the outage probability is

$$P_{OUT} = P(\chi_t < N\frac{2^{C_{OUT}} - 1}{\gamma}) \tag{12}$$

It is observed that for a given outage capacity, $Tx_N, Rx_N = 1$ antenna system requires Tx_N times more signal-to-noise ratio to provide the same outage probability as a system with $Tx_N = 1, Rx_N$ antenna. This is due to the fact that the capacity formulas are derived for the same total transmission power in both cases.

VII. RESULTS & CONCLUSIONS

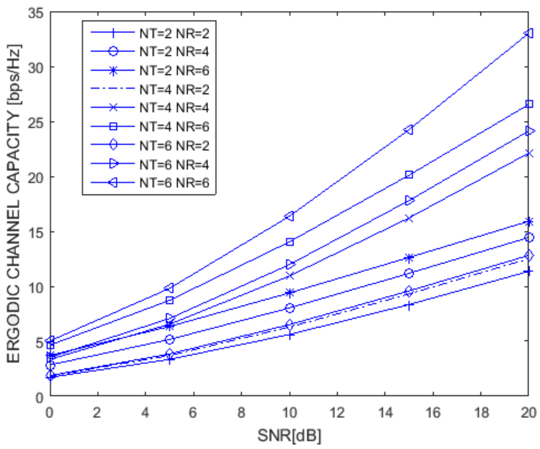

Figure 4: Ergodic Channel Capacity [bps/Hz] Versus SNR [dB] for different Tx_N-Rx_N Pairs

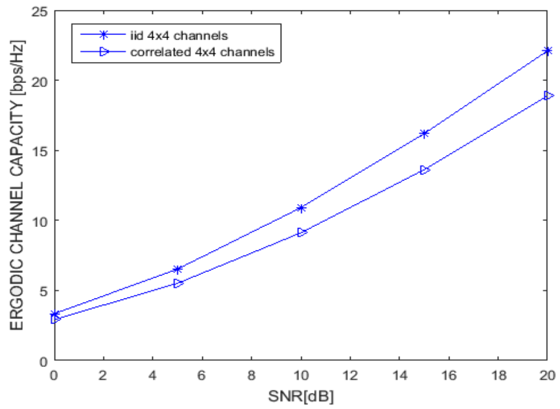

Figure 5: Ergodic Channel Capacity [bps/Hz] Versus SNR [dB] for4X4 Uncorrelated and Correlated Rayleigh Fading Channel

Ergodic and outage capacities for MIMO system has been explored for different system parameter. It has been found that the capacity was improved when CSI information was known at the transmitter. By varying the number of the transmitting antenna a considerable gain in the system capacity is obtained when fixing the number of the receiving antenna.

It can be shown from figure 4 that by increasing the number of transmitter and receiver antennas, channel capacity increases, especially increasing Rx_N results in more capacity as compared to $Tx_{N.}$ Also, it can be that at SNR of 20dB, it is possible to achieve capacity of the order of 33.5bps/Hz for a 6x6 antenna configuration. Finally, MIMO channel capacity will decrease, when the correlated factor increase as depicted in figure 5.

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